FIG. 1

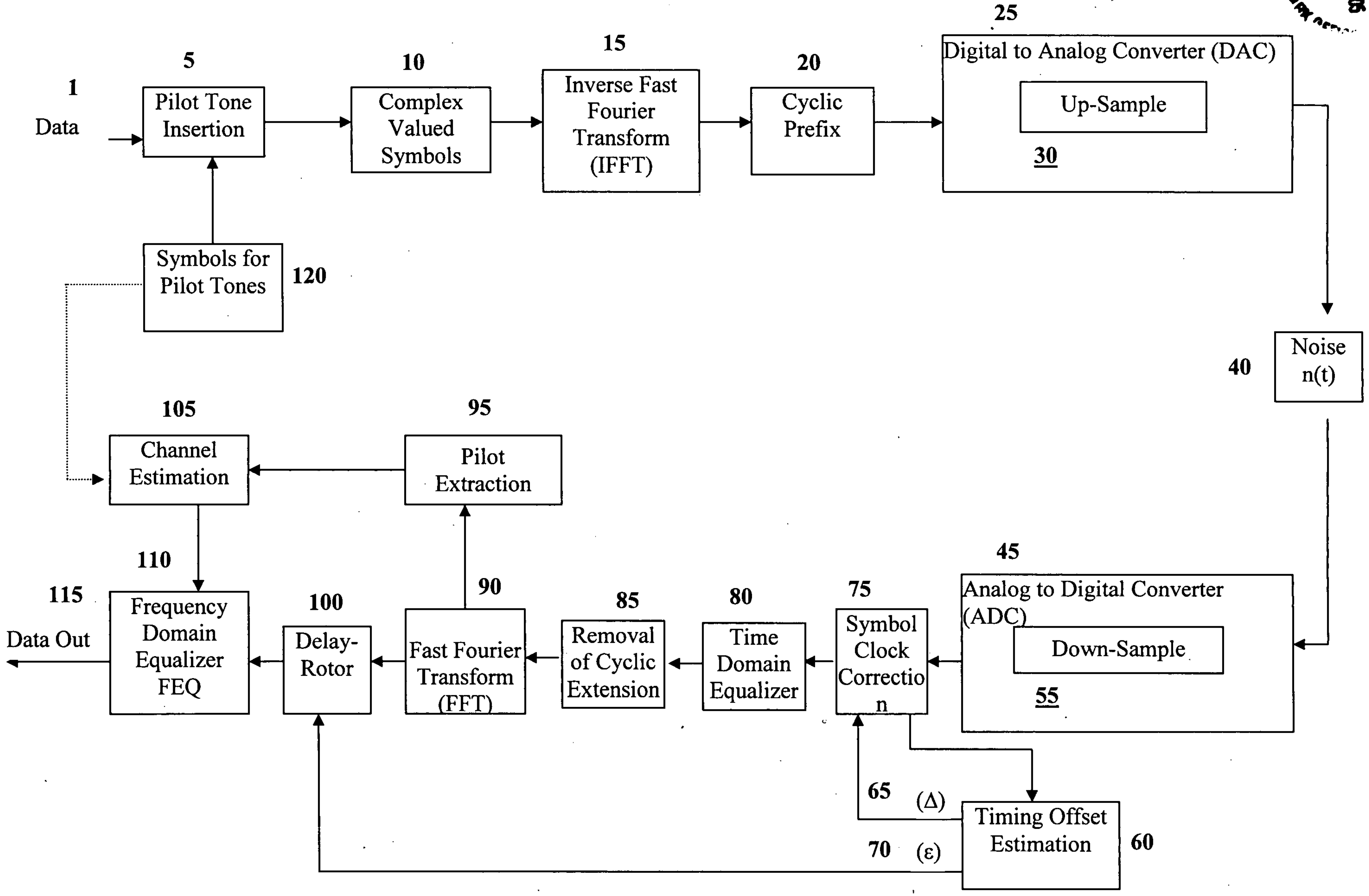

1
Data
5
Pilot Tone Insertion
10
Complex Valued Symbols
15
Inverse Fast Fourier Transform (IFFT)
20
Cyclic Prefix
25
Digital to Analog Converter (DAC)
Up-Sample
30
120
Symbols for Pilot Tones
40
Noise n(t)
45
Analog to Digital Converter (ADC)
Down-Sample
55
75
Symbol Clock Correctio n
80
Time Domain Equalizer
85
Removal of Cyclic Extension
90
Fast Fourier Transform (FFT)
95
Pilot Extraction
100
Delay-Rotor
105
Channel Estimation
110
Frequency Domain Equalizer FEQ
115
Data Out
60
Timing Offset Estimation
65
(Δ)
70
(ε)

FIG. 2

$$x_n = \sqrt{N}\sum_{k=0}^{N-1} X_k e^{j\frac{2\pi kn}{N}}, n=0,\ldots,N-1$$ 2-1

where subscript n and k denote time index and sub-carrier index, respectively.

$\underline{X}^m$ is generated such

$$\begin{cases} X^m_0 = X^m_N = 0 \\ X^m_k = a^m_k, k < N \\ X^m_{N+k} = (a^m_{N-k})^* \end{cases}$$ 2-2

$$x^m_{-k} = x^m_{N-k}$$ 2-3

If the Channel Impulse Response (CIR) is denoted by vector $\underline{h} = [h_0, \ldots, h_{N_c-1}]$, then the received signal can be written as 2-4

$$y_n = h_n x_n + n_n$$

where n_n is the noise sample at n-th time instant.

$$Y_k = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} x_n e^{-j\frac{2\pi kn}{N}}, k=0,\ldots,N-1$$ 2-5

$$Y^m_k = H_k X^m_k + N^m_k, k=0,\ldots,N-1$$ 2-6

Here, uppercase letters represent FFT of the corresponding time-domain signals.

FIG. 3

$$R(\hat{D}) = \sum_{n=0}^{LP-1} r(n+\hat{D}) r(n+N+\hat{D}); \quad \hat{D} = 0,1,\cdots,\hat{D}_{\max}$$ 3-1

where $r(n)$ is the received signal sample at n-th instant, $\hat{D}_{\max}$ is the maximum possible delay. From the correlation function values for various delays, $\hat{D}$ is selected where the function has the maximum value.

3-2

$$\{i, \quad i+N/L \quad \cdots \quad i+N-N/L\}, i = 0,1, \ldots, N/L-1.$$

$$R^m{}_k = H_k + \frac{V^m{}_k}{|X^m{}_k|}, k = 0,\ldots,N-1$$ 3-3

where $R^m{}_k = \dfrac{Y_k^m}{X_k^m}$ and $V^m{}_k = \dfrac{N_k^m}{e^{j\angle X_k^m}}$

Where vectors $\underline{\hat{h}} = [h_0 \quad h_1 \quad \cdots \quad h_{L-1}]$ and $\underline{R}_{pl} = [R_i \quad R_{i+N/L} \quad \cdots \quad R_{i+N-N/L}]$, and the matrix Q_{pl} is defined as:

$$Q_{pl} = \frac{1}{\sqrt{N}} \begin{bmatrix} 1 & W_N^i & \cdots & W_N^{i(L-1)} \\ 1 & W_N^{(i+N/L)} & \cdots & W_N^{(i+N/L)(L-1)} \\ \cdots & \cdots & \cdots & \cdots \\ 1 & W_N^{(i+N-N/L)} & \cdots & W_N^{(i+N-N/L)(L-1)} \end{bmatrix}$$ 3-4

where $W_N = e^{-j\frac{2\pi}{N}}$.

FIG. 4

$$MSE_{normalized} = \frac{\mathrm{E}\left\|\hat{h} - h\right\|^2}{\mathrm{E}\left\|h\right\|^2} \qquad 4\text{-}1$$

where $\underline{h}$ is the actual channel and $\hat{\underline{h}}$ is the MMSE estimation

4-2

$$C_k = \frac{1}{H_k} \quad , k = 0,1, \ldots, N-1$$

$$C_k = \frac{H_k^*}{\left|H_k\right|^2 + \sigma_n^2 / \sigma_a^2} \qquad 4\text{-}3$$

FIG. 5

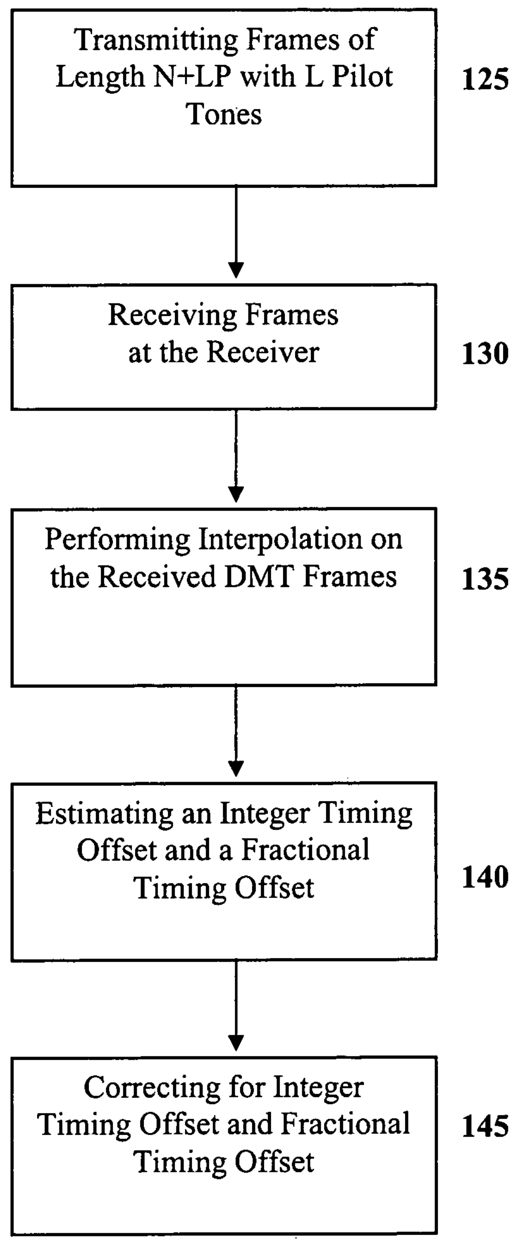

Transmitting Frames of Length N+LP with L Pilot Tones
125
Receiving Frames at the Receiver
130
Performing Interpolation on the Received DMT Frames
135
Estimating an Integer Timing Offset and a Fractional Timing Offset
140
Correcting for Integer Timing Offset and Fractional Timing Offset
145

FIG. 6

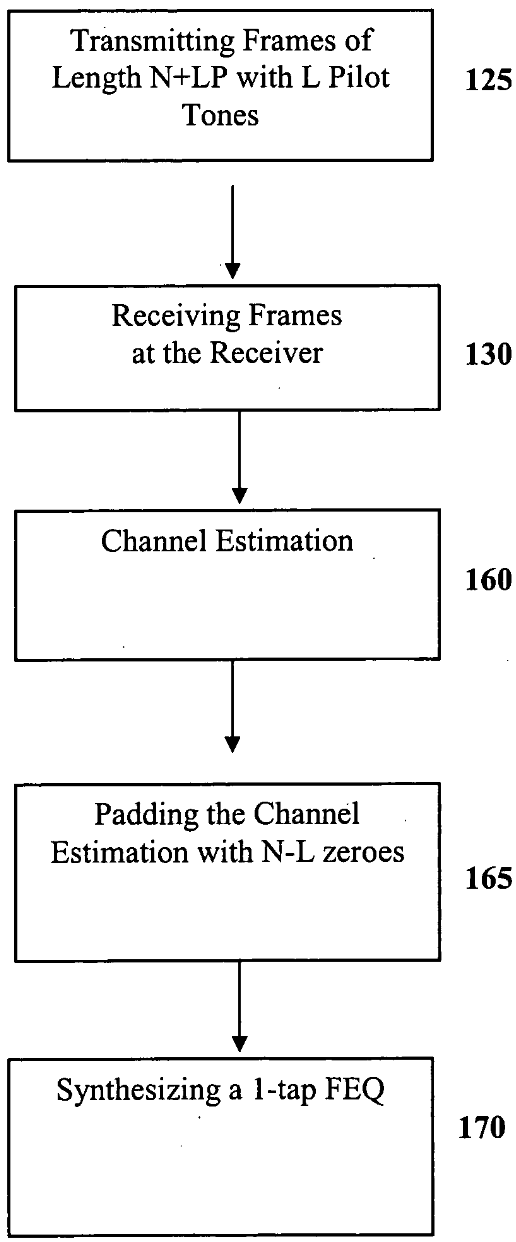

Transmitting Frames of Length N+LP with L Pilot Tones
125
Receiving Frames at the Receiver
130
Channel Estimation
160
Padding the Channel Estimation with N-L zeroes
165
Synthesizing a 1-tap FEQ
170

FIG. 7

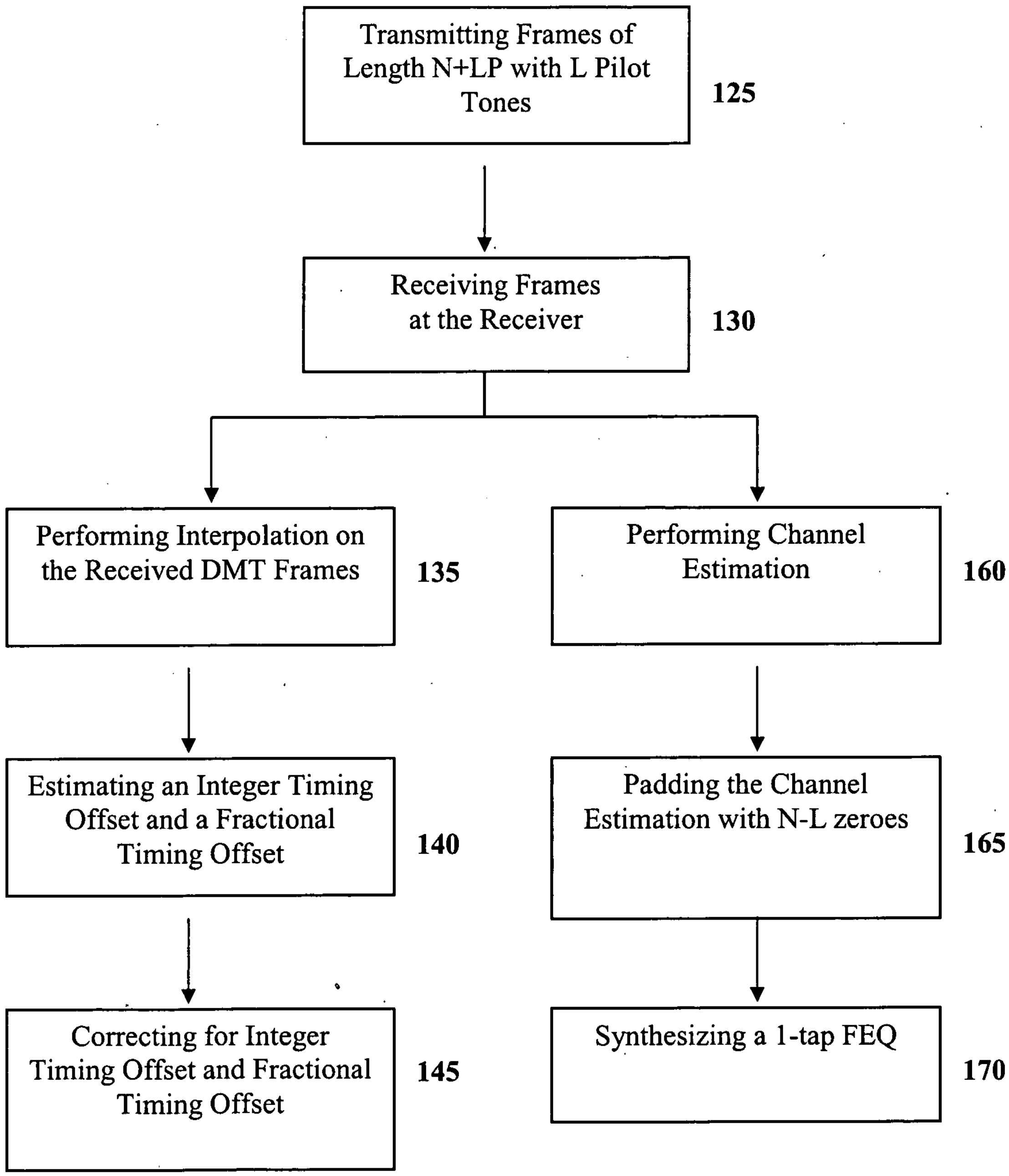

Transmitting Frames of Length N+LP with L Pilot Tones
125
Receiving Frames at the Receiver
130
Performing Interpolation on the Received DMT Frames
135
Estimating an Integer Timing Offset and a Fractional Timing Offset
140
Correcting for Integer Timing Offset and Fractional Timing Offset
145
Performing Channel Estimation
160
Padding the Channel Estimation with N-L zeroes
165
Synthesizing a 1-tap FEQ
170

FIG. 8

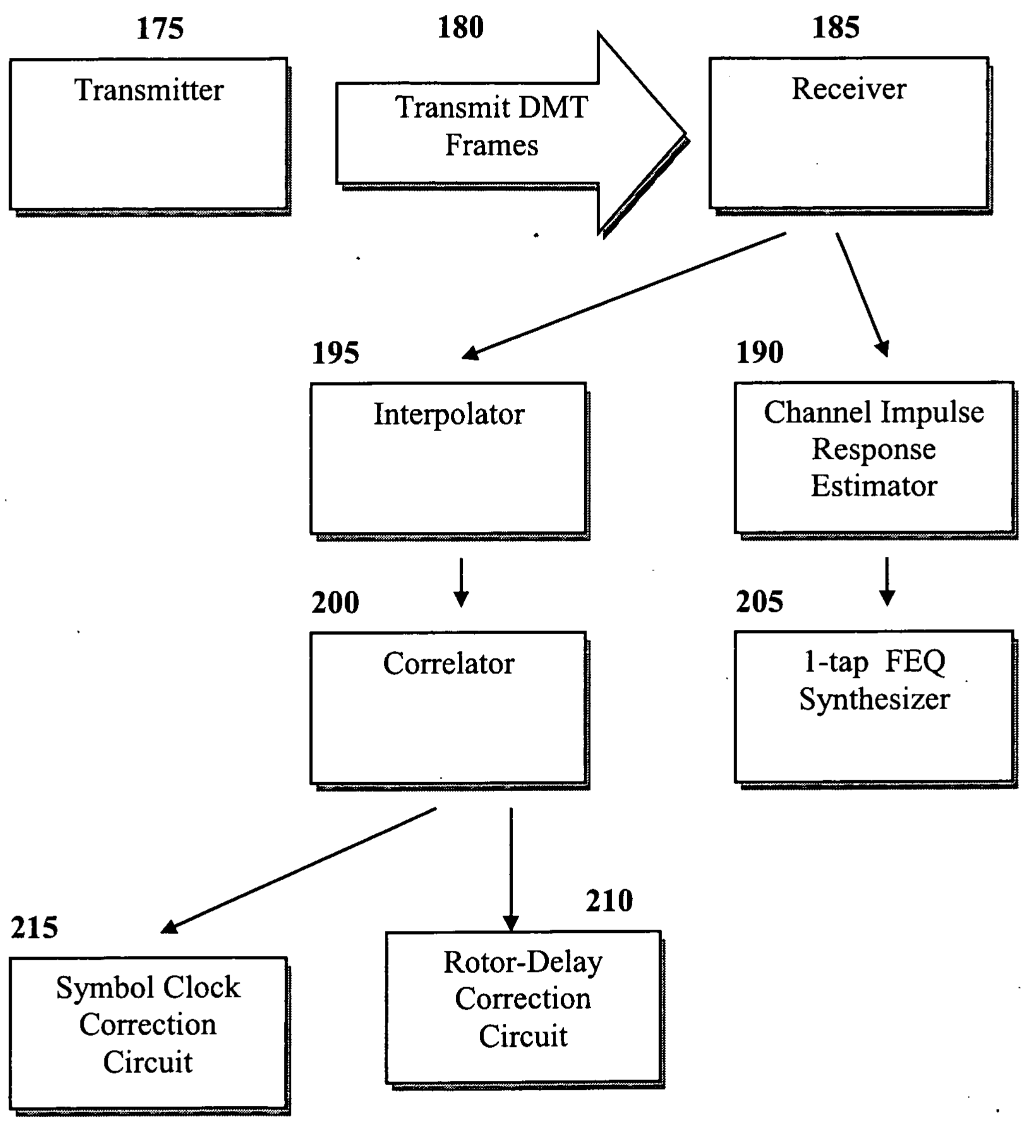

175
Transmitter
180
Transmit DMT Frames
185
Receiver
195
Interpolator
190
Channel Impulse Response Estimator
200
Correlator
205
1-tap FEQ Synthesizer
215
Symbol Clock Correction Circuit
210
Rotor-Delay Correction Circuit

FIG. 9

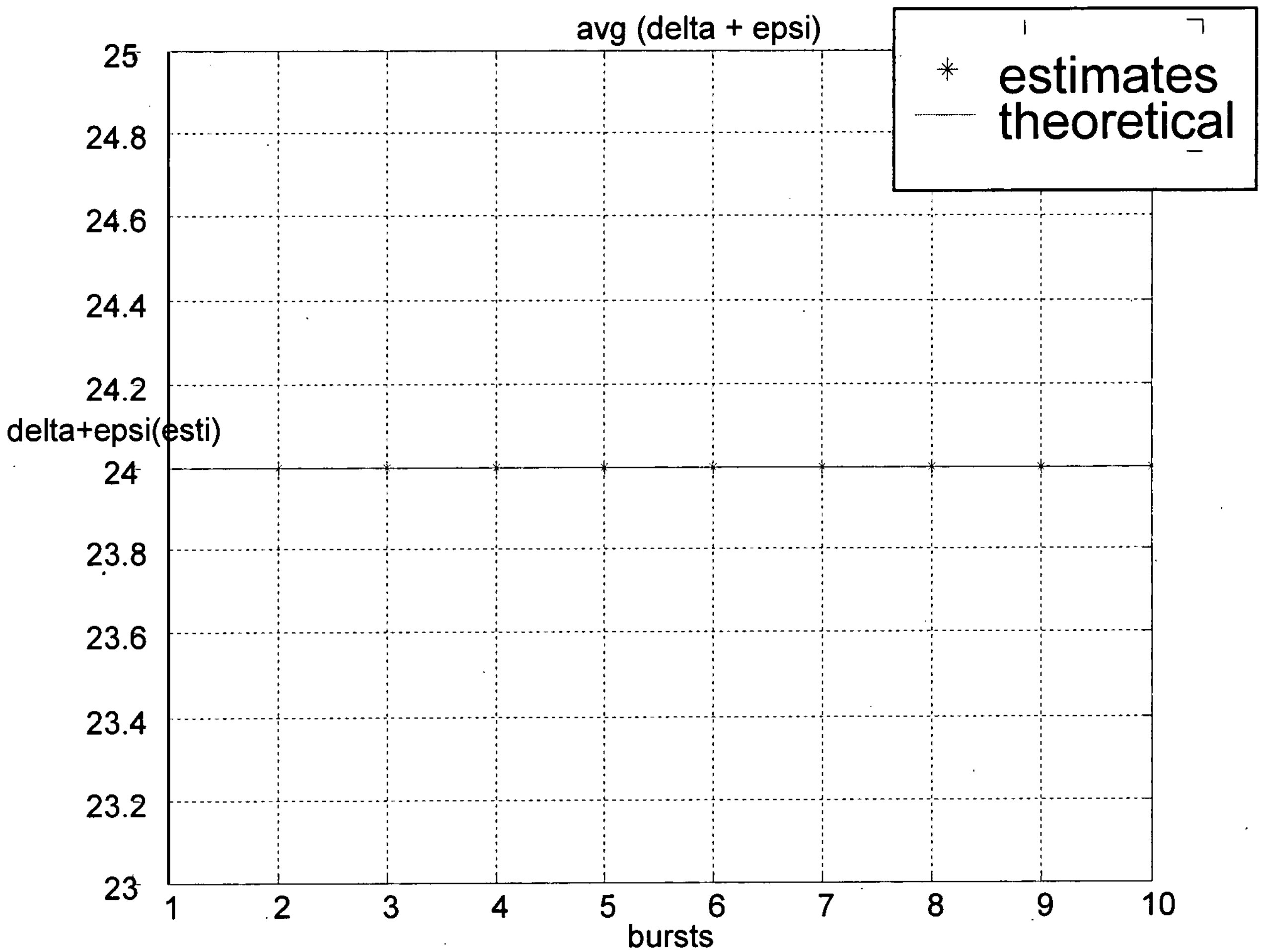

avg (delta + epsi)
estimates
theoretical
delta+epsi(esti)
25
24.8
24.6
24.4
24.2
24
23.8
23.6
23.4
23.2
23
1
2
3
4
5
6
7
8
9
10
bursts

FIG. 10

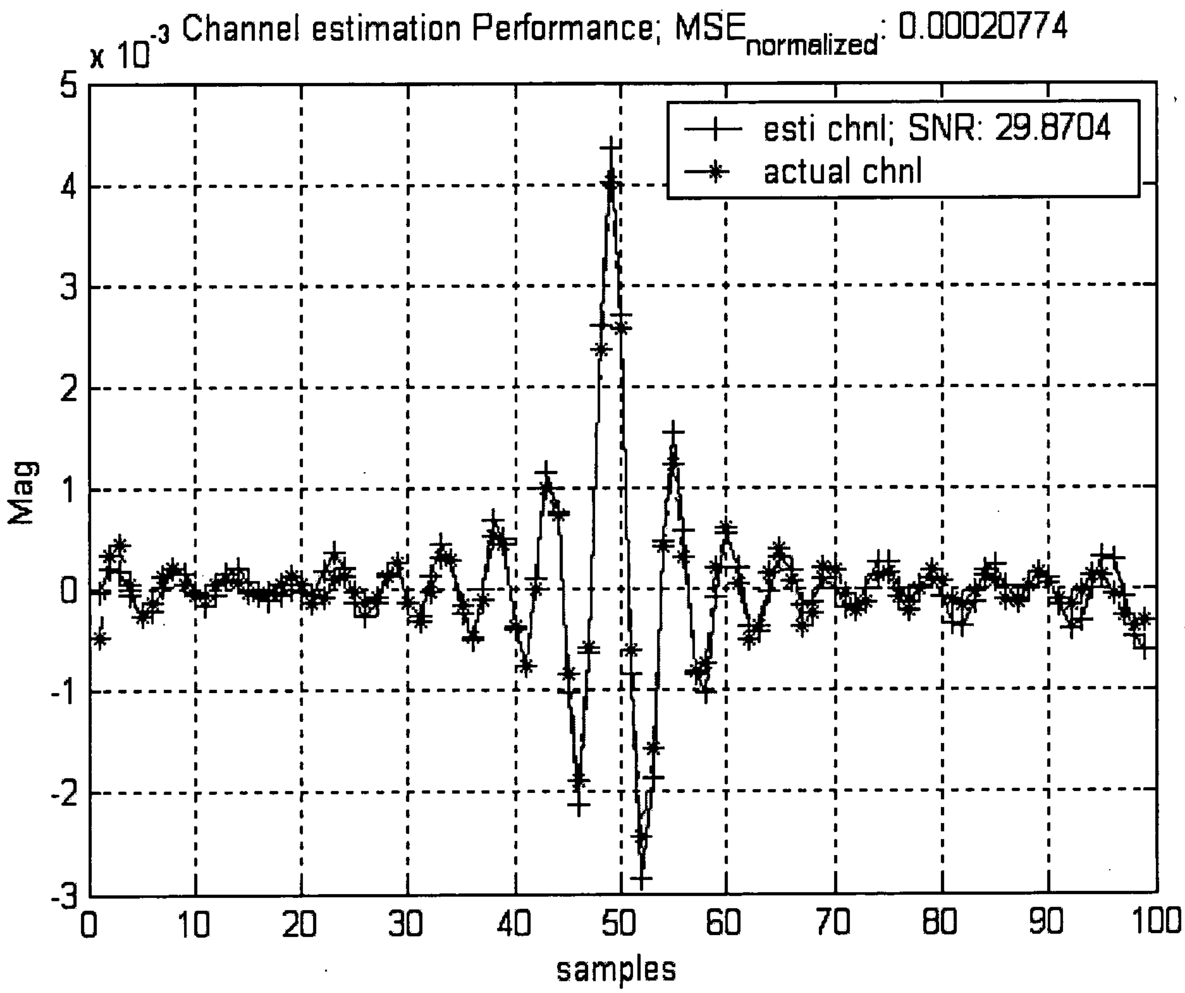
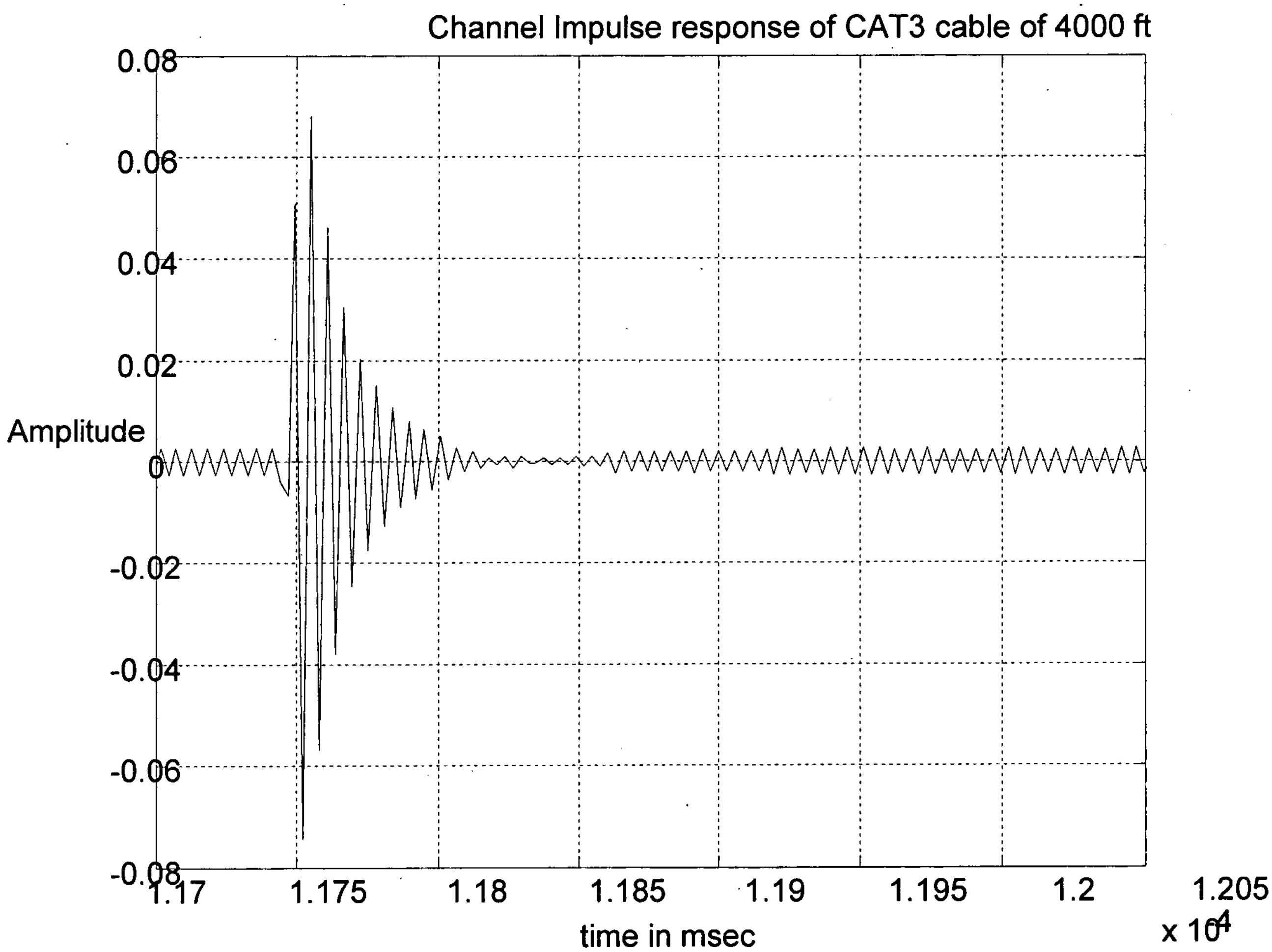

x 10^-3 Channel estimation Performance; MSE normalized: 0.00020774
esti chnl; SNR: 29.8704
actual chnl
Mag
samples
5
4
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60
70
80
90
100

FIG. 11



Channel Impulse response of CAT3 cable of 4000 ft
0.08
0.06
0.04
0.02
Amplitude
0
-0.02
-0.04
-0.06
-0.08
1.17
1.175
1.18
1.185
1.19
1.195
1.2
1.205
time in msec
x 10^4